Toxicity and bioaccumulation potential of Cr (VI) and Hg (II) on differential concentration by Eichhornia crassipes in hydroponic culture
A. K. Giri and R. K. Patel

ABSTRACT
In this work, the phytoremediation of Cr (VI) and Hg (II) ion from water by an aquatic plant Eichhornia crassipes has been studied. Plants were cultured in a double distilled water with modified Hoagland’s nutrient solution at pH 6.8 supplemented with 0, 0.75, 1.50, 2.50, and 4 mg Cr/L as potassium dichromate (K2Cr2O7) and 0, 5, 10, 15, and 20 mg Hg/L as mercuric chloride (HgCl2). They were separately harvested after 3, 6 and 9 days. Plants treated with 4 mg/L of Cr (VI) accumulated the highest concentration of metal in roots (1.22 mg/g, dry weight) and shoots (0.24 mg/g, dry weight) after 9 days; while those treated with 20 mg/L of Hg (II) accumulated the highest concentration of metal in roots (2.43 mg/g, dry weight) and shoots (2.43 mg/g, dry weight) after 9 days. Eichhornia crassipes biomass was characterised using AAS, SEM and FTIR. The accumulation and relative growth of metal ions at different concentrations of chromium and mercury solution significantly increased (P < 0.05) with the passage of time. The maximum values of bio-concentration factor (BCF) for Cr (VI) and Hg (II) were found to be 413.33 and 502.40 L/kg respectively.

Key words | accumulation, bio-concentration, chromium (VI), Eichhornia crassipes, mercury (II), phytoremediation

INTRODUCTION
Rapid industrialisation and urbanisation have caused the elevated emission of toxic heavy metals which has increased the load in the biosphere. Recently considerable interest has been shown in developing cost effective and environmentally friendly technologies for the remediation of soil and waste water, polluted with toxic metals, which is known as phytoremediation. Eichhornia crassipes is a floating macrophyte whose appetite for nutrients and explosive growth rate have been put to use in cleaning municipal and agriculture waste water (Reddy & Debusk 1984). Eichhornia crassipes (family Pontederiaceae) are abundant in wetlands, lakes and ditches. E. crassipes has fibrous root system and broad leaves which have a tendency to tolerate high metal concentration and that is why it is considered as an important species to be used for the study of phytoremediation (Malik 2007). Some macrophytes are found to remove different concentrations of heavy metals, which makes them suitable to act as bio-monitors for metals, and have ability to act as biological filters of the aquatic environment (Maine et al. 2004; Skinner et al. 2007). Chromium is a naturally occurring element found in rocks and minerals. Moreover the metals has also been released from different industrial activity. Toxicity of chromium to plants depends on its valence state; Cr (VI) is highly toxic and mobile whereas Cr (III) is less toxic. Cr (VI) is considered the most toxic form of Cr, which usually occurs associated with oxygen as chromate (CrO4²⁻) or dichromate (Cr2O7²⁻) oxanions. Cr (III) is less mobile, less toxic and is mainly bound to organic matter in soil and aquatic environments (Shanker et al. 2005). Chromium can also contaminate soil, sediment, and ground water (Mei et al. 2002). Mercury has reached unacceptably high levels in the environment due to industrial, agricultural and municipal activities. In nature,
mercury exists in several forms: 1) as ionic salts in either the mercurous (I) or mercuric (II) states, 2) as an organometallic compound such as methyl mercury, or 3) as elemental mercury Hg (0) in either liquid or vapour phase (Boening 2000). Plants engineered to express some of its metabolic activity could have potential for relatively inexpensive clean-up of mercury contaminated sites. Volatilisation of elemental mercury would allow mercury to diffuse out of the plant and into the atmosphere at non-toxic concentrations (Bizily et al. 2000). A plant-based phytoremediation approach to heavy metals uses plant roots to extract, the vascular system to transport and the leaves as a sink to concentrate the elements above ground for harvest and processing. The use of hydroponic culture has been suggested as a means of assessing the plant tolerance to the toxic elements or its efficiency in mineral utilisation. Hydroponic cultures allow easy observation, making quick screening on the basis of relative growth rate and toxicity. The aim of the present study was (i) to evaluate the removal of Cr (VI) and Hg (II) with different concentration by *Eichhornia crassipes* from water; (ii) to study the phytoremediation potential of *Eichhornia crassipes* and relative growth of control and treated plants.

**MATERIALS AND METHODS**

**Experimental procedure**

Young aquatic plants *Eichhornia crassipes* were collected from ponds near civil township, Rourkela. The plants were placed in cement tanks with tap water under natural sunlight for one week to allow them to adapt to the new environment, and then plants of the same variations in size of 10 to 11 cm root length and 6 to 7 cm shoot length were selected for further experiment. A stock solution (1,000 mg/L) each was prepared in distilled water with analytical grade of K₂Cr₂O₇ (MG7M571737) and HgCl₂ (obtained from Merck Specialties) which was later diluted as required. The experiments were conducted in a rectangular glass container (12 × 10 × 8 cm) containing nutrient solutions prepared with double distilled water. The rectangular glass container was kept in a growth room at 25 ± 2°C lighted with cool, fluorescent lamp (55 μmol m⁻² s⁻¹) under 16 h photoperiod. The modified Hoagland nutrient solution consists of 4.0 mM Ca(NO₃)₂, 2.0 mM MgSO₄, 4.0 mM KNO₃, 0.4 mM (NH₄)₂SO₄, 2 μM MnSO₄, 0.3 μM CuSO₄, 0.8 μM ZnSO₄, 30 μM NaCl, 0.1 μM Na₂MoO₄, 1.43 μM KH₂PO₄, 10 μM H₃BO₃ and 20 μM Fe-Na-EDTA (All obtained from Merck specialties) (Hoagland & Arnon 1950). pH of the solution was measured by pH meter (Orion two stars, USA). The pH of the nutrient solution was adjusted to 6.8 using 0.1 N HCl or 0.1 N KOH. The solution was changed regularly at 3-day intervals to maintain the desired pH. The plants were maintained in deionised water supplemented with 0, 0.75, 1.50, 2.50, and 4 mg Cr/L as potassium dichromate (K₂Cr₂O₇) and 0, 5, 10, 15, and 20 mg Hg/L as mercury chloride (HgCl₂). They were separately harvested after 0, 3, 6 and 9 days. Deionised water was added daily to compensate the water loss through plant transpiration, sampling and evaporation. All experiments were performed in triplicate. They were separated into shoots and roots and analysed for relative growth, metals accumulation, toxicity and bio-concentration factor (BCF). In addition, the residual metals in the solution were measured to assess the removal potential of *Eichhornia crassipes*.

**Sample analysis**

**Metals accumulation**

Metals accumulation in plant and water samples was measured. Digestion of samples in this study was performed according to the standard method (APHA 1998). Plant samples were decomposed to dry matter by heating at 120°C for 24 hours in a hot air oven and the ash was digested with nitric acid and filtered into a volumetric flask with the help of Whatman filter paper 42. The final volume was made up with deionised water and metals analyses were carried out by using flame atomic absorption spectrophotometer (FAAS) (Perkin-Elmer P 200). The results of the accumulation were reported as concentration (mg/g), dry weight of Cr (VI) and Hg (II) in plants.

**Relative growth**

The relative growth of plant species is a major factor to contributing to invasion. Relative growth of control and treated plants was calculated as follows (Lu et al. 2004; James & Drenovsky 2007): the results of the increases of biomass per unit mass per day (g·g⁻¹·d⁻¹).

Relative growth = \( \frac{\text{Final fresh weight (FFW)}}{\text{Initial fresh weight (IFW)}} \)

**Bio-concentration Factor**

The BCF provides an index of the ability of the plant to accumulate the metal with respect to the metal concentration...
in the substrate. The result of BCF was calculated (L/kg) as follows (Zayed et al. 1998).

\[
BCF = \frac{\text{Concentration of metal in plant tissue (mg/kg)}}{\text{Initial concentration of metal in external solution (mg/L)}}
\]

Statistical analysis

The mean numbers of relative growth, metal concentration and BCF were calculated and subjected to analysis of variance (ANOVA) using randomised block design and least significance difference method (LSD) on the MINITAB for windows software program. (Winer 1981).

RESULTS AND DISCUSSION

Characterisation of *Eichhornia crassipes* biomass.

SEM analysis

The scanning electron micrographs-energy dispersive X-ray spectroscopy (SEM) were obtained at 1000 × magnification of the surface of the *Eichhornia crassipes* biomass before and after absorptions of metal ions at pH 6.8 using a JEOL JSM-6480 LV scanning electron microscope. Figure 1(a) clearly reveals the surface texture and different levels of porosity in the materials before absorption of metal ions. It is evident that the carbon particles are in the form of spheres with a wide range of sizes (Sinha et al. 2003). Figure 1(b) and (c) clearly indicates the presence of new shiny bulky particles over the surface of metal loaded biomass which are absent in the original biomass. So, it was concluded that the chromium and mercury ions absorbed on the surface of *Eichhornia crassipes* biomass.

FTIR analysis

Infrared spectra of the *E. crassipes* biomass with and without chromium and mercury loaded were obtained to determine which functional groups may have contributed to the Cr (VI) and Hg (II) ions absorption on the *E. crassipes* biomass. The FTIR spectra of the biomass without Cr (VI) and Hg (II) loaded displays a number of absorption peaks, indicating the complex nature of the biomass, using PerkinElmer FTIR spectrophotometer SPECTRUM RX-I. The peak at 2,918.50 cm\(^{-1}\) indicates –CH stretching vibration of alkyl chains. The absorption peak appear at 1,645.17 cm\(^{-1}\) may be due to C=O stretching vibration of carboxylic or ester groups. The absorbance peaks at 1,418.56 cm\(^{-1}\) may be attributed to N-H stretching vibration, –CH\(_2\) scissoring or –CH\(_3\) anti-symmetrical bending vibration and O-H
deformation. The peaks at 1,172.97 and 1,008.50 cm\(^{-1}\) may be attributed to C-N stretching vibration of amino group. The weak absorption peak at 671.85 and 633.04 cm\(^{-1}\) was probably attributed to O–C–O scissoring vibration of polysaccharide such as chitin or similar compound.

The spectrum of the chromium (VI) loaded biomass, when compared with that of biomass without chromium, is shown in Figure 2. There is a significant shift of few absorption peaks indicating the coordination of metal to biomass. The band at 2,918.50 cm\(^{-1}\) has been shifted insignificantly. The peaks at 1,645.17 cm\(^{-1}\) have been shifted to 1,638.96 cm\(^{-1}\), may be due to the complexation of carboxylic group with Cr (VI). Another shift was observed from 1,418.96 cm\(^{-1}\) to 1,319.75 cm\(^{-1}\), corresponding to the complexation of nitrogen with chromium from the N-H group. Another shift was observed from 1,172.97 to 1,163.54 cm\(^{-1}\) and 1,008.50 to 1,022.47 cm\(^{-1}\), maybe due the interaction of nitrogen from amino group with chromium. The other weak absorption peak shifted from 671.85 to 670.09 cm\(^{-1}\) and 633.04 to 632.40, corresponding to the O–C–O scissoring vibration of polysaccharide. The above changes in the spectra may be attributed to the interaction of Cr (VI) with the carboxyl, hydroxyl and amino groups present on the surface of the E. crassipes biomass (Kim et al. 2004; Bansal et al. 2009; Qaiser et al. 2009). This clearly manifests the binding of chromium to the biomass.

Relative growth

The effects of Cr (VI) and Hg (II) as relative growth of Eichhornia crassipes at different metal concentrations and exposure times were shown in Figure 4(a) and (b). The relative growth of control plants significantly increased (P < 0.05) with the passage of time. In plants treated with K\(_2\)Cr\(_2\)O\(_7\), the relative growth significantly increased (P < 0.05) in 0.75, 1.50, 2.50 mg/L treatments, but decreased in 4 mg/L treatments.

![Figure 2](image2.jpg) FTIR spectra of the Eichhornia crassipes biomass without (control) and with (4 mg/L) loaded chromium ions at pH 6.8.

![Figure 3](image3.jpg) FTIR spectra of the Eichhornia crassipes biomass without (control) and with (20 mg/L) loaded mercury ions at pH 6.8.

![Figure 4](image4.jpg) The effects of Cr (a) and Hg (b) on relative growth of Eichhornia crassipes at different metal concentrations and exposure times.
In plants treated with HgCl₂, the relative growth significantly increased (P < 0.05) in 5, 10, 15 and 20 mg/L treatments. P value is less than 0.05 level, which indicates that the results which are calculated and shown have 95% significance. The highest values of relative growth were 1.32 and 1.34 g/g d. for *Eichhornia crassipes* treated with K₂Cr₂O₇ at 2.5 mg/L and HgCl₂ at 20 mg/L, respectively. The comparison of maximum relative growth of water exposed to K₂Cr₂O₇ (2.5 mg/L) and HgCl₂ (20 mg/L) is shown in Table 1. The best long-term strategy for improving phytoextraction is to understand and exploit the biological processes involved in metal acquisition, transport and shoot accumulation. In the present study, the relative growth increased in plants treated with concentrations of K₂Cr₂O₇ of 0.75, 2.5, 1.5 mg/L, but decreased in 4 mg/L as shown in Figure 4(a). It appears that low concentration could stimulate plant growth. This is due to higher concentration levels of heavy metal ions having inhibitory effects on plant metabolic activity, alternatively reducing growth of plants, leaf necrosis and inhibiting the plant physiology systems. Cr(VI) tolerance and accumulation in selected *Eichhornia crassipes* growth are mainly by suppressing development of new roots and reducing relative growth rates to about 15% of those of controls (Stratford et al. 1984; Schat et al. 1996). In plants treated with HgCl₂ the relative growth increased in 5, 10, 15 and 20 mg/L treatments, as shown in Figure 4(b). The addition of HgCl₂ at low concentration had a favourable effect on the growth of *Eichhornia crassipes*. Plants exposed to ionic mercury through the root exhibit reduced growth of shoots and roots (Zaranyika & Ndapwadza 1995). Plants, accumulation of higher concentration levels of mercury ions has inhibitory effects on all enzyme activity, loss of chlorophyll and checks the plant respiration.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>K₂Cr₂O₇ concentration mg/L</th>
<th>Maximum growth response</th>
<th>HgCl₂ concentration mg/L</th>
<th>Maximum growth response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative growth (g/g.d.)</td>
<td>2.5</td>
<td>1.32</td>
<td>20</td>
<td>1.34</td>
</tr>
<tr>
<td>Metals accumulation (mg/g, dry weight)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoot</td>
<td>4</td>
<td>0.24</td>
<td>20</td>
<td>2.43</td>
</tr>
<tr>
<td>Root</td>
<td>4</td>
<td>1.22</td>
<td>20</td>
<td>4.22</td>
</tr>
<tr>
<td>BCF (L/kg)</td>
<td>1.5</td>
<td>413.33</td>
<td>5</td>
<td>502.40</td>
</tr>
</tbody>
</table>

**Table 1** | Maximum growth response of *Eichhornia crassipes* exposed to Cr (VI) and Hg (II) culture

![Figure 5](https://iwaponline.com/wst/article-pdf/63/5/899/445380/899.pdf)

**Figure 5** | The accumulation of Cr (VI) ions at pH 6.8 in shoots (a) and roots (b) of *Eichhornia crassipes* biomass.

Chromium hexavalent, mercury divalent translocation and accumulation.

Cr (VI) and Hg (II) accumulation by *Eichhornia crassipes* at different concentrations and exposure times are separately shown in Figure 5 and Figure 6 respectively. In general, there was increase in the metal accumulation in shoots and roots when metal concentration and exposure times were increased (P < 0.05). For Cr (VI), control and plants treated with 0.75, 1.5, 2.5 and 4 mg/L showed a significant difference (P < 0.05) in metal accumulation, as shown in Figure 5(a) and (b). There was a significant difference (P < 0.05) in Cr (VI) accumulation with the passage of time at all concentrations. For Hg (II) significant differences (P < 0.05) between control and treated plants were found at all metal concentrations, as shown in Figure 6(a) and (b). Plants treated with 4 mg/L of Cr (VI) on days 9 accumulated the highest level of metal in shoots (0.24 mg/g, dry weight; Figure 5(a)) and in roots (1.22 mg/g, dry weight; Figure 5(b)); while plants treated with 20 mg/L of Hg (II) on day 9 accumulated the highest level of metal in shoots (2.43 mg/g, dry weight; Figure 6(a)) and in roots (4.22 mg/g, dry weight; Figure 6(b)). See bioaccumulation and toxicity of mercury in rooted submerged macrophyte *Vallisneria spiralis* (Gupta & Chandra 1998). The comparison of maximum accumulation of Cr (VI) and Hg (II) in *Eichhornia...
Eichhornia crassipes exposed to K$_2$Cr$_2$O$_7$ (4 mg/L) and HgCl$_2$ (20 mg/L) is shown in Table 1. In the present study, *Eichhornia crassipes* accumulated the highest concentration of metals in roots (1.22 mg/g, dry weight for Cr (VI) and 4.22 mg/g, dry weight for Hg (II)). However, a relatively small amount of Cr (VI) (0.24 mg/g, dry weight) was translocated to the shoot, while Hg (II) was translocated at a much higher concentration (2.43 mg/kg, dry weight). This result demonstrated that Hg (II) was much more mobile than Cr (VI). The accumulation of metals in the roots and shoots of *Eichhornia crassipes* has been shown in field studies in which it was used as a biological monitor in metal pollution (Benhammou et al. 2005). The uptake of Cr, both by roots and shoots, increased with increasing metal concentration in the external medium but the uptake was not linear in correlation to the increase in concentration. The metals accumulation in water hyacinth increased linearly with the solution concentration in the order of leaves < stems < roots in *Eichhornia crassipes* (Qian et al. 1999). In the present study the mass balance of Cr (VI) and Hg (II) in various parts of the *E. crassipes* plants remained in water tank and gas phase as shown in Table 2. Metal ions penetrated plants by passive process, mostly by exchange of cations which occurred in the cell wall. All heavy metals were taken up by plants through absorption, translocation and released by excretion (Zhu et al. 1999). In the present study, although Cr (VI) and Hg (II) translocation to the plant aerial parts occurred continuously during the whole experiment, it was slower than sorption by roots. Cr (VI) accumulation in 4 mg/L treated plants reached the highest level in roots and shoots presented in Figure 5(a) and (b). For Hg (II) accumulation, 20 mg/L treated plants reached the highest level in shoots and roots presented in Figure 6(a) and (b). In presence of excessive oxygen chromium (III) oxidises into Cr (VI), which is highly toxic and more soluble in water than the other forms. Chromium (VI) can easily cross the cell membrane, whereas the phosphate-sulphate carrier also transports the chromite anions. Fe, S, and P are known also

![Figure 6](image_url) The accumulation of Hg (II) ions at pH 6.8 in shoots (a) and roots (b) of *Eichhornia crassipes* biomass.

### Table 2 | Mass balance of Cr (VI) and Hg (II) in various parts of *Eichhornia crassipes* plants, remaining in water tank and gas phase

<table>
<thead>
<tr>
<th></th>
<th>Root (mg/L)</th>
<th>Stem (mg/L)</th>
<th>Leaves (mg/L)</th>
<th>Remaining in water tank (mg/L)</th>
<th>Remaining in gas phase (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cr (VI)</strong> mg/L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.75</td>
<td>0.670</td>
<td>0.042</td>
<td>0.025</td>
<td>0.010</td>
<td>0.003</td>
</tr>
<tr>
<td>1.50</td>
<td>1.252</td>
<td>0.104</td>
<td>0.060</td>
<td>0.072</td>
<td>0.012</td>
</tr>
<tr>
<td>2.50</td>
<td>2.090</td>
<td>0.157</td>
<td>0.101</td>
<td>0.132</td>
<td>0.020</td>
</tr>
<tr>
<td>4</td>
<td>3.266</td>
<td>0.182</td>
<td>0.110</td>
<td>0.400</td>
<td>0.040</td>
</tr>
<tr>
<td><strong>Hg (II)</strong> mg/L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>3.114</td>
<td>0.412</td>
<td>0.186</td>
<td>1.183</td>
<td>0.110</td>
</tr>
<tr>
<td>10</td>
<td>5.414</td>
<td>1.120</td>
<td>0.760</td>
<td>2.545</td>
<td>0.167</td>
</tr>
<tr>
<td>15</td>
<td>8.086</td>
<td>1.958</td>
<td>1.244</td>
<td>3.485</td>
<td>0.227</td>
</tr>
<tr>
<td>20</td>
<td>10.150</td>
<td>2.925</td>
<td>2.023</td>
<td>4.432</td>
<td>0.449</td>
</tr>
</tbody>
</table>
to compete with Cr for carrier binding (Wang & Lewis 1997).
Plants exposed to ionic mercury through the root exhibit
reduced growth of shoots and roots. Mercury-resistant bac-
teria have been reported to produce enzymes that catalyse
two reactions: 1) organomercurial lyase—which removes
methyl groups from mercury to create ionic mercury, and 2)
mercuric ion reductase which converts ionic mercury to
volatile elemental mercury (Bizily et al. 1999). It can be
proposed that the roots reached saturation during the period
and there exists some mechanism in roots that could detoxify
heavy metals or transfer them to aerial parts.

Toxic effects of chromium and mercury in plants.

Chromium detoxification and remediation.
The toxic effects of Cr are primarily dependent on the metal
speciation, which determines its uptake, translocation and
accumulation mechanism. The oxidation state of chromium
strongly influences the rate of chromium uptake. Chromium
(VI) can easily cross the cell membrane and the phosphate
sulphate carrier transports the chromate ion. It forms a
number of stable oxyacids and anions, including HCrO4
(Hydrochromate), Cr2O72− (dichromate), and CrO42− (chro-
mate). The chromate ion has a large ionic potential and
tetrahedral coordination and acts both as strong acid and
an oxidising agent. The toxic properties of Cr (VI) originate
from the action of this form itself as an oxidising agent, as
well as from the formation of free radicals during the reduc-
tion of Cr (VI) to Cr (III) inside the cell. Induction and
activation of superoxide dismutase (SOD) and of antioxidant
catalase are some of major metal detoxification mechanisms
in plants shown in Figure 7. Plasma membrane ATPase plays
a significant role in the adaptation to heavy metal conditions
and it is regulated at the molecular and biochemical levels
reaction as follows (Shanker et al. 2005a).

\[
\begin{align*}
K_2Cr_2O_7 & \rightarrow Cr_2O_7^{2−} + 2K^+ \\
2Cr_2O_7^{2−} + 28H^+ & \xrightarrow{\text{(Induction & activation of SOD)}} \rightarrow 4Cr^{3+} + 14H_2O
\end{align*}
\]

(1)
(2)

Mercury detoxification and remediation
The toxic effects of Hg are primarily dependent on the metal
speciation, which determines its uptake, translocation and
accumulation mechanism. Mercury transformation and
remediation system in plants is responsible for the protono-
lysis of HgCl2 and reduced to form ionic mercury Hg (II).
The properties and chemical behaviour of mercury strongly
depend on its oxidation state. Mercury ions reductase
removes mercury from stable thiol salts by electrochemically
reducing it to the less toxic, relatively volatile metallic mer-
ccury Hg (0) in an NADPH coupled redox reaction which is
shown in Figure 7. Hg (0) is nearly two orders of magnitude
less toxic than ionic mercury and is readily eliminated by
plants due to its volatility. The scheme of reaction as follows
(Dhankher & Meagher 2005):

\[
\begin{align*}
HgCl_2 + 2H^+ & \rightarrow Hg(II) + 2HCl \\
Hg(II) + NADPH & \xrightarrow{\text{(Electrochemically reductase)}} Hg(0) + NADP^+ + H^+
\end{align*}
\]

(3)
(4)

Effects of TDS and DO
The results of the effects of total dissolved solids (TDS) and
dissolved oxygen (DO) on the Eichhornia crassipes without
and with nutrient solution of control, Cr (VI) and Hg (II)
containing water tank after 9 days is shown in Table 3. TDS
consists of CaNO3, MgSO4, KNO3, (NH4)2SO4, MnSO4,
CuSO4, ZnSO4, NaCl, Na2Mo4, KH2PO4, H3BO3 and Fe-
Na-EDTA ions. The increasing of TDS increased the
growth of E. crassipes containing Cr (VI) and Hg (II)
ions. It may be due to the presence of suitable cations and
anions that have influencing effect on the nutrient uptake.
The comparison of dissolved oxygen without and with
containing Cr (VI) and Hg (II) reveals that uptake of
metal ions increases with increasing dissolved oxygen
value than. It may be due to the molecular oxygen enhan-
cing the binding to the site of metal ions.
Bio-concentration factor

The BCF values for Cr (VI) and Hg (II) at different concentrations and exposure times were shown in Figure 8(a) and (b). BCF is a useful parameter to evaluate the potential of the plants in accumulating metals. In general, the BCF values for Cr (VI) and Hg (II) increase with the passage of time (P < 0.05). The BCF values for Cr (VI) significantly increased (P < 0.05) with Hg (II) concentration in the feed solution at each exposure time. The maximum BCF of 502.40 L/kg was found in plants treated with 5 mg/L of HgCl₂ on day 9 (Figure 8(b)). The comparison of maximum BCF of *Eichhornia crassipes* exposed to K₂Cr₂O₇ (1.5 mg/L) and HgCl₂ (5 mg/L) is shown in Table 1. Bio-concentration factor (BCF) is a useful parameter to evaluate the potential of the plants in accumulating metals and this value was calculated on a dry weight basis. The BCF values of *Eichhornia crassipes* were very high for Cd, Cu, Cr and Se at low external concentration, and they were found to decrease as the external concentration increased (Zhu et al. 1999). In the present study, for plants treated with Cr (VI), the BCF values decreased when Hg (II) concentration increased. For plants treated with Cr (VI), the BCF values first increased with the increase of Cr concentration, and then decreased when Cr concentration was over 1.50 mg/L, as presented in Figure 8(a). It can be concluded that the best BCF value was obtained when the external solution concentrations were 1.50 mg/L for Cr (VI) and 5 mg/L for Hg (II), as presented in Figure 8(b). When the metal concentration in water increases the amount of metal accumulation in plants increases, whereas the BCF values decreases (Wang & Lewis 1997). The maximum BCF values for Cr (VI) and Hg (II) were 413.33 and 502.40 L/kg, respectively, indicating that *Eichhornia crassipes* can be used for effective phytoremediation. It represents a cost-effective plant-based technology for the removal of metals from the environment and has great potential for future applications.

**CONCLUSION**

*Eichhornia crassipes* used in ‘Eco-technology’ for phyto-extraction and phytofiltration are the best-developed subsets for removal of toxic metals from environment. Nutrient culture is an efficient method for screening heavy metal ions tolerant for free floating plants of *Eichhornia crassipes* in hydroponic culture. The mechanisms of uptake, translocation and detoxification of Cr (VI) and Hg (II) ions are well shown in plant root cells. The metal uptake was ascertained by adopting various characterisation methods like AAS, SEM and FTIR of the biomass before and after treatment. Least significant difference of relative growth, metal accumulation and BCF versus different concentrations of

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**Table 3** Results of TDS and DO without and with nutrient solution of control, Cr (VI) and Hg (II) containing water tank after 9 days

<table>
<thead>
<tr>
<th></th>
<th>TDS (ppm)</th>
<th>DO (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without metal ions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>nutrient solution container</td>
<td>75</td>
<td>4.54</td>
</tr>
<tr>
<td>Control (nutrient solution)</td>
<td>750.23</td>
<td>5.73</td>
</tr>
<tr>
<td>With nutrient solution container</td>
<td>762.42</td>
<td>6.64</td>
</tr>
<tr>
<td>Cr (VI)</td>
<td>765.52</td>
<td>6.67</td>
</tr>
<tr>
<td>Hg (II)</td>
<td></td>
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</tr>
</tbody>
</table>

**Figure 8** The bio-concentration factor (BCF) values of Cr (VI) (a) and Hg (II) (b) at pH 6.8 in *Eichhornia crassipes* at different metal concentrations and exposure times.
chromium and mercury solution at 3, 6, and 9 days of exposure reveals P<0.05. In the present work, the chromium (VI) and mercury (II) ions accumulation and tolerance efficiency by the plants are above 95%. Further studies are necessary on adsorption of activated carbon of the *Eichhornia crassipes* biomass.

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**REFERENCES**


